

IMPLICATIONS OF ULTRAHEAVY COSMIC-RAY SOURCE COMPOSITION DERIVED FROM OBSERVATIONS BY THE HEAO-3 HEAVY NUCLEI EXPERIMENT

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ABSTRACT

We have derived the contribution of r-process and s-process nucleosynthesis to the Cameron (1980) solar system (SS) abundances for $Z \geq 33$. In the interval $34 \leq Z \leq 40$ our HEAO-3 data extrapolated to the cosmic-ray source (CRS) fit the solar system mix better than r-process. In the interval $26 < Z < 40$ the HEAO-3 results for CRS/SS follow the same general correlation with first ionization potential as for the lighter elements although there are deviations in detail.

1. Solar-System Decomposition to r and s

The Cameron (1980) elemental abundances were decomposed into r-process, s-process, and p-process components following the general approach of Seeger *et al.* (1965). For isotopes made by both r- and s-processes, the s-process contribution was inferred by interpolation between pure s-process isotopes on the smoothed σN_s vs A curve, (where N_s is the s-process abundance of an isotope of atomic weight A , and σ is the 30 keV Maxwellian-averaged neutron capture cross-section for that isotope given by Allen *et al.* (1971)). The difference between this s-process contribution and the total Cameron (1980) abundance of that isotope was assigned to the r-process. Abundances of other isotopes could be uniquely assigned to a single process. Total contributions from each process to all stable or very long-lived isotopes of each element were then summed. The r and s results are shown in Table 1. (SS gives solar system abundance from Cameron (1980) normalized to 10^6 at ^{14}Si .) Figure 1 shows the solar system abundances used here and the r-process contribution.

The neutron capture cross-sections used here have significant uncertainties which can have a major effect on the s-process subtraction. For example, $^{80}_{34}\text{Se}$ is the most abundant isotope of this element. For this element, the Allen *et al.* (1970) value of σ is 20 ± 12 mb. If instead of using 20 mb, as was done in deriving the values in Table 1, we had used 32 mb for this isotope and left all other σ unchanged, then the r-process component of Se would be 42% of the element instead of 27%. Thus there are substantial uncertainties in the r and s components for many individual elements. Nevertheless, the broad features of the breakdown are not affected by these uncertainties.

Table 1

Z	SS	r	s	Z	SS	r	s
33	6.2	3.6	2.6	60	0.79	0.37	0.42
34	67	18	48	62	0.24	0.16	0.07
35	9.2	7.1	2.1	63	0.094	0.090	0.004
36	41.3	24.7	15.5	64	0.42	0.38	0.03
37	6.1	5.1	1.0	65	0.076	0.074	0.002
38	22.9	2.4	20.3	66	0.37	0.31	0.06
39	4.8	1.7	3.1	67	0.092	0.087	0.005
40	12	3	9	68	0.23	0.20	0.03
41	0.9	0.7	0.2	69	0.035	0.03	0.004
42	4.0	1.6	1.4	70	0.20	0.14	0.06
44	1.9	1.3	0.5	71	0.035	0.029	0.006
45	0.40	0.34	0.06	72	0.17	0.10	0.07
46	1.3	0.6	0.7	73	0.020	0.011	0.009
47	0.46	0.33	0.13	74	0.30	0.21	0.09
48	1.55	0.75	0.77	75	0.054	0.047	0.007
49	0.19	0.12	0.06	76	0.69	0.63	0.06
50	3.7	1.1	2.5	77	0.72	0.71	0.01
51	0.31	0.25	0.06	78	1.41	1.36	0.05
52	6.5	5.5	1.0	79	0.21	0.20	0.01
53	1.27	1.22	0.05	80	0.21	0.10	0.11
54	5.84	4.66	1.17	81	0.19	0.14	0.05
55	0.39	0.36	0.03	82	2.6	1.1	1.5
56	4.8	2.2	2.6	83	0.14	0.12	0.02
57	0.37	0.06	0.31	90	0.045	0.045	-
58	1.2	0.2	1.0	92	0.027	0.027	-
59	0.18	0.07	0.11				

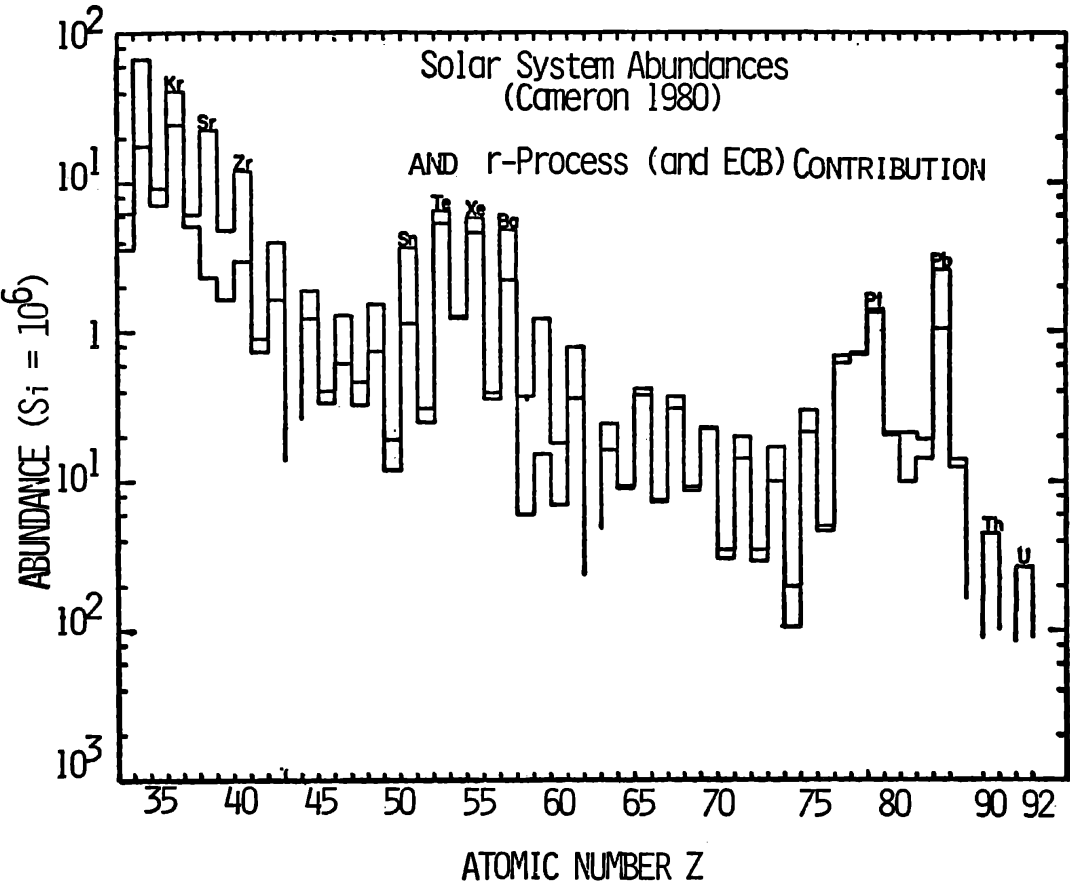


Figure 1

In particular note the very sharp fall-off of r-process abundances above ${}_{36}\text{Kr}$; the r-process abundance of ${}_{38}\text{Sr}$ is about an order of magnitude below that of ${}_{34}\text{Se}$. Our HEAO results (OG H.2-8) show no such drop off, indicating that the cosmic-ray abundances for $Z \leq 40$ are not dominated by r-process.

2. First-Ionization Potential

Cassé and Goret (1978) noted for elements lighter than ${}_{26}\text{Fe}$ a good correlation between first ionization potentials and the ratios of the solar system to cosmic-ray abundances. Our HEAO results (OG H.2-8) are plotted in Figure 2 (large squares) along with earlier data at lower Z (small circles), (Lezniak and Webber, 1978; Young *et al*, 1981.) The ratio of cosmic-ray source to solar system in the interval $26 \leq Z \leq 40$ follows the same general correlation as for lighter elements. Because the elements with high first ionization potential are either noble gases or more likely to form volatile compounds, it has been suggested (Tueller *et al*, 1979; Cesarsky and Bibring 1980; Epstein 1980) that "volatility" may be controlling factor in the comparison between cosmic ray abundances and solar-system abundances. However Figure 2 shows that Ge, which is volatile, is not significantly depleted with respect to Fe, which is not volatile.

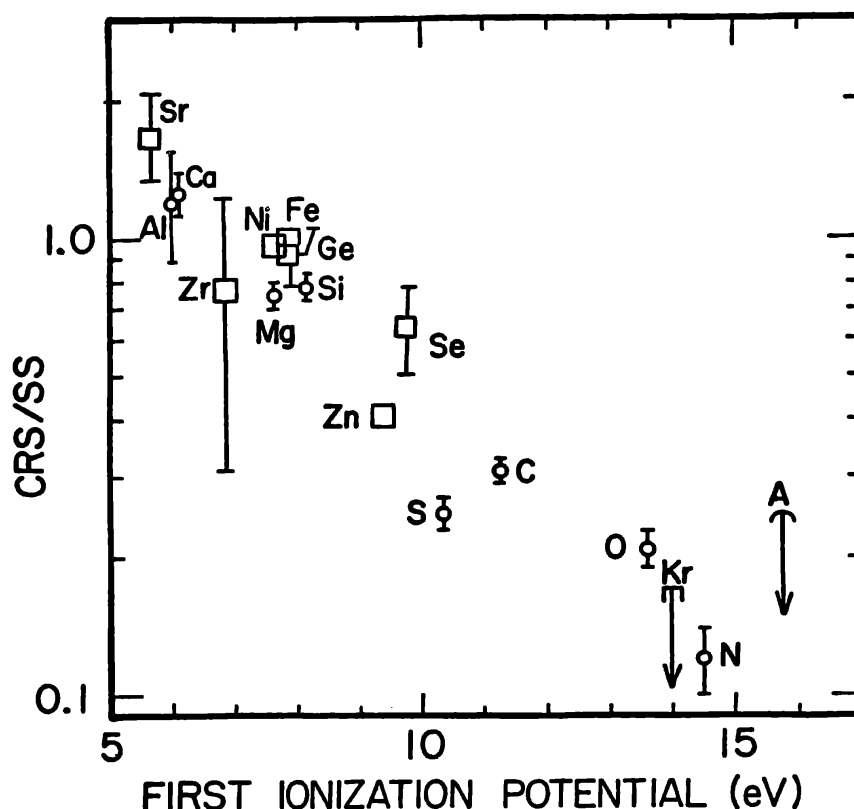


Figure 3

The observation that the first ionization potential provides a general organization of the abundance ratio suggests that the abundances may be affected by a preferential injection mechanism during the acceleration process. However, there are discrepancies in the detailed correlation. For example, Zn, Se, and S have similar ionization potentials but quite different abundance ratios. Such discrepancies suggest that there may be differences not related to first ionization potential between the cosmic-ray-source abundances and current estimates of solar-system abundances. Improved statistics and extension of the current results to higher charges should permit the identification of any nucleosynthesis contribution to these abundance differences.

3. Acknowledgment

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References

- Allen, B. J., Gibbons, J. H., and Macklin, R. L. 1971, Adv. Nucl. Phys., 4, 205.
- Cameron, A. G. W. 1980, Center for Astrophysics Preprint No. 1357.
- Cassé, M. and Goret, P. 1978, Ap. J., 221, 703
- Cesarsky, C. J. and Bibring, J. P. 1980, IUPAP/IAU Symposium 94, Bologna.
- Epstein, R. I. 1980, Nordita preprint 80/12.
- Lezniak, J. A. and Webber, W. R. 1978, Ap. J. 223, 676.
- Seeger, P. A., Fowler, W. A., and Clayton, D. D. 1965, Ap. J. Suppl. 11, 121.
- Tueller, J., Love, P. L., Israel, M. H., and Klarmann, J. 1979, Ap. J. 228, 580.
- Young, J. S., Freier, P. S., Waddington, C. J., Brewster, N. R., and Fickle, R. K. 1981, Ap. J. to be published June 15.